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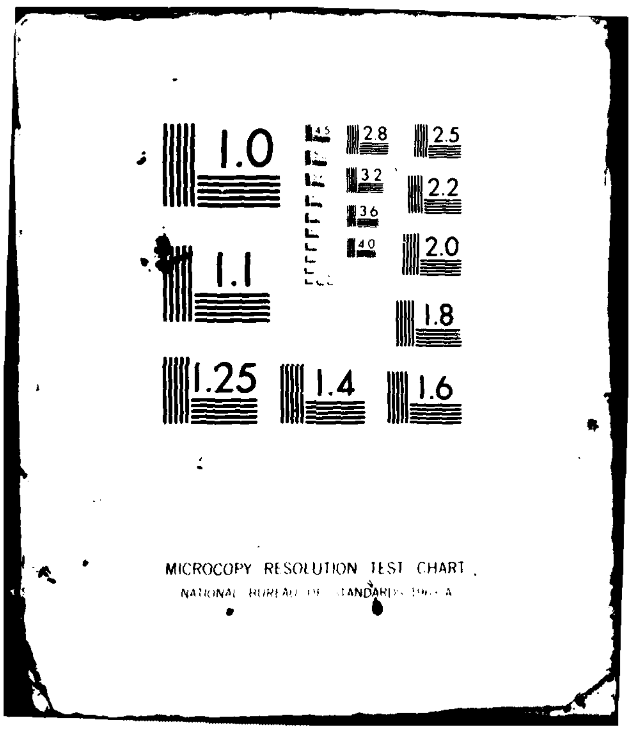
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MAY 1980

STRUCTURAL ENGINEERING

STEEL STRUCTURES

DESIGN MANUAL 2.3

APPROVED FOR PUBLIC RELEASE

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Basic criteria for the design of structural elements and systems fabricated of various alloys of structural steel are presented for use by experienced engineers. Design standards are established for Class A (Bridge), Class B (Building), and Class C (Special) structures. A discussion of special considerations related to the design of certain types of steel structures such as crane runways, towers, stacks, and storage tanks is included. Problems of corrosion, abrasion, design of expansion joints, and exposure to extreme temperatures are discussed.

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FOREWORD

This design manual is one of a series developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command, other Government agencies, and the private sector. This manual uses to the maximum extent feasible, national professional society, association, and institute standards in accordance with NAVFACENGCOM policy. Deviations from these criteria should not be made without prior approval of NAVFACENGCOM Headquarters (Code 04).

Design cannot remain static any more than can the naval functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged from within the Navy and from the private sector and should be furnished to NAVFACENGCOM Headquarters, Code 04. As the design manuals are revised, they are being restructured. A chapter or a combination of chapters will be issued as a separate design manual for ready reference to specific criteria.

This publication is certified as an official publication of the Naval Facilities Engineering Command and has been reviewed and approved in accordance with SECNAVINST 5600.16.

D. G. Iselin

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Rear Admiral, CEC, U.S. Navy
Commander
Naval Facilities Engineering Command

STRUCTURAL ENGINEERING DESIGN MANUALS

New DM Number	Superseded Chapter in Basic DM	Subject
2.1	-	General Requirements
2.2	1	Loads
2.3	2	Steel Structures
2.4	3	Concrete Structures
2.5	4	Timber Structures
2.6	5, 6, 7, 8	Aluminum Structures Masonry Structures Composite Structures Other Structural Materials
2.7	-	Snow Loads (Tri-Service)

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STEEL STRUCTURES

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FIGURES

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TABLE

Section 1. SCOPE AND RELATED CRITERIA

1. SCOPE. This manual prescribes criteria for the design of structures, including temporary and prefabricated structures, which are fabricated of "Structural Steel" and related materials.

2. CANCELLATIONS. This manual, NAVFAC DM-2.3, Steel Structures, cancels and supersedes Chapter 2 of Structural Engineering, NAVFAC DM-2, of October 1970, and Changes 1 and 2.

3. RELATED CRITERIA. Certain criteria related to the design of steel structures appear in other manuals in the design manual series and in other sources as follows:

Subject	Source
General Requirements Service Classifications and Other General Requirements	NAVFAC DM-2.1
Soil Mechanics, Foundations and Earth Structures	NAVFAC DM-7
Fire Protection Engineering Fire Protection	NAVFAC DM-8
Electronics Industries Association Towers	RS-222
Bridges	1) AASHTO "Standard Specifications for Highway Bridges" 2) AREA "Manual for Railway Engineering"
Storage Tanks	1) NAVFAC DM-22 Liquid Fueling and Dispensing Facilities 2) AWWA Standard, "Welded Steel Elevated Tanks, Standpipes and Reservoirs for Water Storage" 3) API Standard 650 "Welded Steel Tanks for Oil Storage"
Corrosion Prevention and Control	NAVFAC MO-306

Subject	Source
Cold Regions Engineering . . . . Design in Arctic and Antarctic Areas	NAVFAC DM-9
Structural Steel	1) AISC "Manual of Steel Construction," "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings" 2) ASCE "Plastic Design in Steel" 3) AISC/SJI "Standard Specifications for Open Web Joists," "Standard Specifications for Longspan Steel Joists" 4) AISI "Cold Formed Steel Design Manual" 5) SDI "Steel Roof Deck Design Manual" 6) MBMA "Recommended Design Practices Manual"
Cables	AISI "Manual for Structural Application of Steel Cables for Buildings"

4. STANDARD SPECIFICATIONS. Throughout this manual, where design criteria are obtained from cited sources, those citations are termed "Standard" Specifications.

5. MINIMUM CONNECTIONS. There shall be a minimum of two fasteners in any connection (not including pinned, welded, or glued connections), except for secondary bracing members such as lacing and battens and except for incidental connections (not including primary bracing members) not proportioned on the basis of calculated stress.

Section 2. DESIGN STANDARDS

Part 1. CLASS A STRUCTURES

1. HIGHWAY BRIDGES. AASHTO "Standard Specifications for Highway Bridges" shall apply.

2. RAILWAY BRIDGES. AREA Standard "Manual for Railway Engineering" shall apply.

3. OTHER. Unless special considerations exist, the AASHTO "Standard Specifications for Highway Bridges" shall apply. Specifically, the AASHTO Standard may be followed in the design of structures supporting equipment moving on tracks if the provisions for distribution of concentrated loads are modified to reflect the effects of the tracks.

Part 2. CLASS B STRUCTURES

1. STRUCTURAL STEEL. AISC Standard "Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings" and related standards as published in the AISC "Manual of Steel Construction" shall apply. Analysis and design of steel structures on the basis of plastic design, as described in ASCE "Plastic Design in Steel" and AISC "Plastic Design of Braced Multistory Steel Frames" may be followed.

2. STEEL JOISTS. AISC/SJI "Standard Specifications for Open Web Joists," "Standard Specifications for Longspan Steel Joists" and "Standard Specifications for Deep Longspan Steel Joists" shall apply.

3. LIGHT GAGE COLD-FORMED STEEL. AISI "Cold-Formed Steel Design Manual" shall apply.

4. STEEL ROOF DECK. SDI "Steel Roof Deck Design Manual" shall apply.

5. STEEL CABLES. AISI "Manual for Structural Applications of Steel Cables for Buildings" shall apply. Increase factor of safety up to 5 (based on ultimate) for threaded hardware where wind, earthquake, or other vibratory loadings may occur.

6. PREFABRICATED BUILDINGS. For combinations of loads and minimum thicknesses of materials, MBMA publication "Recommended Design Practices Manual" shall apply. Design loadings shall be as specified in NAVFAC DM-2.2, except as follows: where use of design loadings specified in NAVFAC DM-2.2 would prevent procurement of available off-the-shelf buildings, subject to review and approval by Code 04 (Structural) consideration may be given to deviation from said loadings. Type of occupancy should be among the factors considered in determining whether deviation is permissible. The reader is cautioned to check the loadings used in the design of prefabricated buildings against the requirements of NAVFAC DM-2.2, modified as set forth in paragraph 12 (Exceptions for Minor Structures) of NAVFAC DM-2.1.

7. DESIGN ASSUMPTIONS APPLICABLE TO CRANE RUNWAY BEAMS AND SUPPORTS.

a. Runway Stops. Provide removable stops or bumpers at ends of the runway. Design on basis of:

(1) If the stop engages the tread of the wheel, the height shall not be less than the radius of the wheel. Stops engaging other parts of the crane are recommended.

(2) Proportion stops for crane traveling at rated speed, with power off; using coefficient of restitution of 0.5, check for condition of travel at 20 percent of rated speed, with power off, that deceleration does not exceed 3 ft./sec/sec.

b. Deflections. Vertical deflection of crane runway girders should be limited to L/1000. Check horizontal deflection to assure compatibility with clearances between flanges of double-flanged wheels and bearing area of single-flanged wheels.

Part 3. CLASS C STRUCTURES

1. GENERAL. The provisions of the design standards for Class B structures shall apply except as prescribed in NAVFAC DM-2.1 or elsewhere herein.

2. WIRE ROPE. Working loads for various types of wire rope, including guys, but not including running ropes such as in cranes or derricks, and not including wire rope used in other types of equipment or machinery, shall be as follows:

a. Prestretched Zinc-Coated Steel Structural Wire Rope and Strand (ASTM A603, A586, and A475). For guyed towers, the provisions of RS-222 shall apply. For other types of structures, consult NAVFACENGCOM. In general the factor of safety, based on breaking strength, shall not be less than 2.0, and shall be increased for cases where occupied areas would be threatened by failure of the rope or strand.

b. All Other Types of Wire Rope and Wire Strand and All Non-Prestretched Wire Rope and Wire Strand. Consult NAVFACENGCOM.

c. Fasteners. For speltered fasteners, follow recommendations in ASTM Standard applicable to type of rope (or strand) being used. For threaded fasteners in guyed towers, consult NAVFACENGCOM regarding desirability of increasing factor of safety.

3. TOWERS.

a. Towers Over 300 Feet and Commercial Standard Designs. NAVFACENGCOM shall be consulted, on an individual project basis, for the criteria to be used for specific towers over 300 feet in height. To facilitate procurement of standard, commercially manufactured, steel radio towers of 300 feet or less in height, use of the latest Standard RS-222 (Electronic Industries Association) is permitted.

b. Geometry of Free Standing Towers. Taper free standing towers inward toward the top. For high towers, the tapering can consist of two or more slopes. The upper part of the tower can be uniformly shaped. Use a portal base only where functionally required (for access, bringing in equipment, or to straddle an obstruction). Otherwise, connect the bottom struts to the tower legs close to the base.

c. Foundations for Free Standing Towers. For individual leg foundations, the minimum weight of the concrete foundation alone (not considering weight of the earth cover) shall provide a factor of safety of 1.0 against uplift, overturning, and sliding. Factor of safety against uplift, overturning and sliding, including weight of earth cover, shall conform to requirements of DM-2.1 para. 7.

d. Guys. Guys shall be prestretched. Follow recommendations in ASTM Standard applicable to type of rope (or strand) being used.

e. Design Assumptions for Guyed Towers. The following design assumptions should be made:

(1) With no wind and with air temperature at the design value, initial tension in guy cables shall be no more than one-tenth the cable breaking strength.

(2) There should be no increasing of allowable stress due to wind loading except as specified in para. (4).

(3) Working loads for guys shall be as specified in paragraph 2, (Wire Rope). Working loads for insulators and eye bolts of fail-safe insulators shall be 30 percent and 20 percent respectively of the manufacturer's guaranteed minimum breaking strength.

(4) Consider the effect of one guy broken with one-quarter wind load plus dead load, with an increase in allowable stress of 33 percent but not exceeding the yield of the material.

(5) Eccentrically loaded towers should be designed to minimize tower dead load deflections. The design should consider cambering the tower so that introduction of the eccentric dead load will result in a plumb condition.

4. SELF-SUPPORTING STACKS.

a. Local Buckling.

(1) Unstiffened, cylindrical stacks shall be investigated for local buckling due to axial compression and bending when:

D/t is greater than $3300/F_y$.

where:

D = nominal diameter inches
t = wall thickness, inches
F_y = yield strength, ksi

(2) Where the preceding D/t ratio is exceeded, the allowable axial compression and bending stress shall be determined by substituting a reduced effective failure stress Fyr for Fy in the appropriate design formulas of the AISC Standard, where:

$$Fyr = 1 - \left(1 - \frac{3300/Fy}{D/t}\right)^2 Fy$$

b. Beam Shear. An effective shear area of one-half the gross cross-sectional area shall be used when calculating beam shear in the cylinder.

c. Compact Section. Cylindrical stacks may be treated as compact sections when D/t is less than or equal to 1300/Fy.

d. Deflection. Computed deflection at the top of the stack shall not be more than 1/100 of the stack height.

e. Weight of Plate and Lining. Additional compressive stresses in the stack plate due to the weight of the stack plate and light lining (maximum of twice the weight of the stack plate) may be neglected.

f. Wind-Induced Vibration. Effects shall be investigated. In particular, beware of vibration induced by low velocity winds, especially when multiple stacks are in series.[1]

5. STORAGE TANKS.

a. Tanks for Water Storage. The design (both elevated and surface tanks) shall conform to the AWWA Standard "Welded Steel Elevated Tanks, Standpipes, and Reservoirs for Water Storage."

(1) Modifications to the AWWA Standard:

(a) Section 3.2: Substitute the loads indicated in DM-2.2 for the provisions of paragraphs 3.2.3, 3.2.4 and 3.2.5.

(b) Section 3.10: See paragraph 2 of Section 3 for criteria on corrosion. Corrosion allowances shall be added to the flanges of beams and channels as well as to the webs.

(c) Where horizontal girders are used as balcony floors, minimum girder widths shall be as follows:

---

[1]See American Society of Mechanical Engineers Publication 63-WA-248 ("Dynamic Response of Tall Stacks to Wind Excitation") and American Society of Civil Engineers, Proc. Vol. 80, Nov. '54 ("The Vibration of Steel Stacks").

Tank capacity (gallons)	Minimum girder widths (inches)
75,000 or less	24
over 75,000 to 100,000	27
over 100,000 to 200,000	30
over 200,000	36

(d) Thickness of hemispherical bottoms shall be proportioned in accordance with paragraph 5.11 of the AWWA Standard, but not less than the thickness of the lowest shell plate in the cylindrical part.

(e) See paragraph 5. SELF-SUPPORTING STACKS for criteria relating to prevention of local buckling in riser pipe.

(f) Use of high-strength steels covered in the AISC Standard will be permitted.

(2) Design Considerations.

(a) Use all-welded, cylindrical construction unless special conditions dictate otherwise.

(b) Shell design shall consider principal stresses, combining ring stresses and vertical compression, with bending due to restraints offered by top and bottom plates.

(c) Design foundations in accordance with criteria for free standing towers.

b. Tanks for Storage of Liquid Fuel. (See NAVFAC DM-22.)

c. Foundations in Seismic Zones. Ring beams shall be provided for all tank foundations in Zones 3 or 4.

Section 3. SPECIAL CONSIDERATIONS

1. EXPANSION JOINTS.

a. Class A Structures. Applicable requirements of the Standard Specification shall govern provisions for expansion and contraction.

b. Class B Structures. Provide expansion joints:

(1) Where structures are more than 300 feet in length, unless special conditions of climate or exposure exist.

(2) At junctures of T-, L-, U-shaped and other irregularly shaped buildings.

(3) Where there is such a change in the type of foundation construction as to expect differential settlements.

2. CORROSION.

a. Allowance for Corrosion Loss (Carbon Steel-ASTM A36). For purposes of estimating service life, the following provisions may be used as "first approximation." Where serious corrosion problems are anticipated, advice of corrosion specialists should be sought. See also, Corrosion Handbook of American Society of Corrosion Engineers.

(1) Atmospheric Corrosion. See Figure 1 for typical time-corrosion curves for industrial and marine atmospheres for various types of steels. Using these values, multiply by relative corrosive effects of atmospheres at different locations throughout the world as presented in Corrosion Prevention and Control, NAVFAC MO-306, Table 4, to approximate corrosion loss.

(2) Corrosion in Soils. Use Figure 2 to estimate corrosion loss for buried steel. These curves do not include allowance for stray current effects.

(3) Seawater Corrosion. For continuously submerged conditions, the rate of loss for the various types of structural steels is approximately 0.004 inch per year for each surface exposed. In, and above, the splash zone the rate of corrosion loss is greater. It shall be assumed, subject to modification by local experience, that conformance to the provisions of paragraph b. following, and to the supplementary provisions of NAVFAC DM-25, will provide the required service life stipulated in NAVFAC DM-2.1.

(4) Electrolytic Corrosion. Do not use dissimilar materials without proper insulators, or cathodic protection, or both.

(5) Corrosion in Tropical Climates. Except where specific values are presented in Table of NAVFAC MO-306, increase allowance for corrosion loss when designing facility in tropical climate in accordance with local experience. Unless otherwise demonstrable, and excepting arid regions, assume a corrosion loss twice that in comparable exposure in temperate climate.

b. Design Provisions. Where applicable:

(1) Design box-shaped members so that all inside surfaces may be readily inspected, cleaned, and painted; or close them entirely.

(2) In outdoor structures, the flanges of two angle members, if not in contact, shall have a minimum of 3/8 inch of space between them.

(3) Pockets or depressions in outdoor structures shall have drain holes or be filled with concrete, mastic, or grout. Provide positive drainage away from exposed steel. Terminate column bases on concrete curbs or piers above grade, and pitch tops of curbs or piers to drain.

(4) Steel sheet piling should be capped with concrete to eliminate rapid corrosion of the exposed ends.

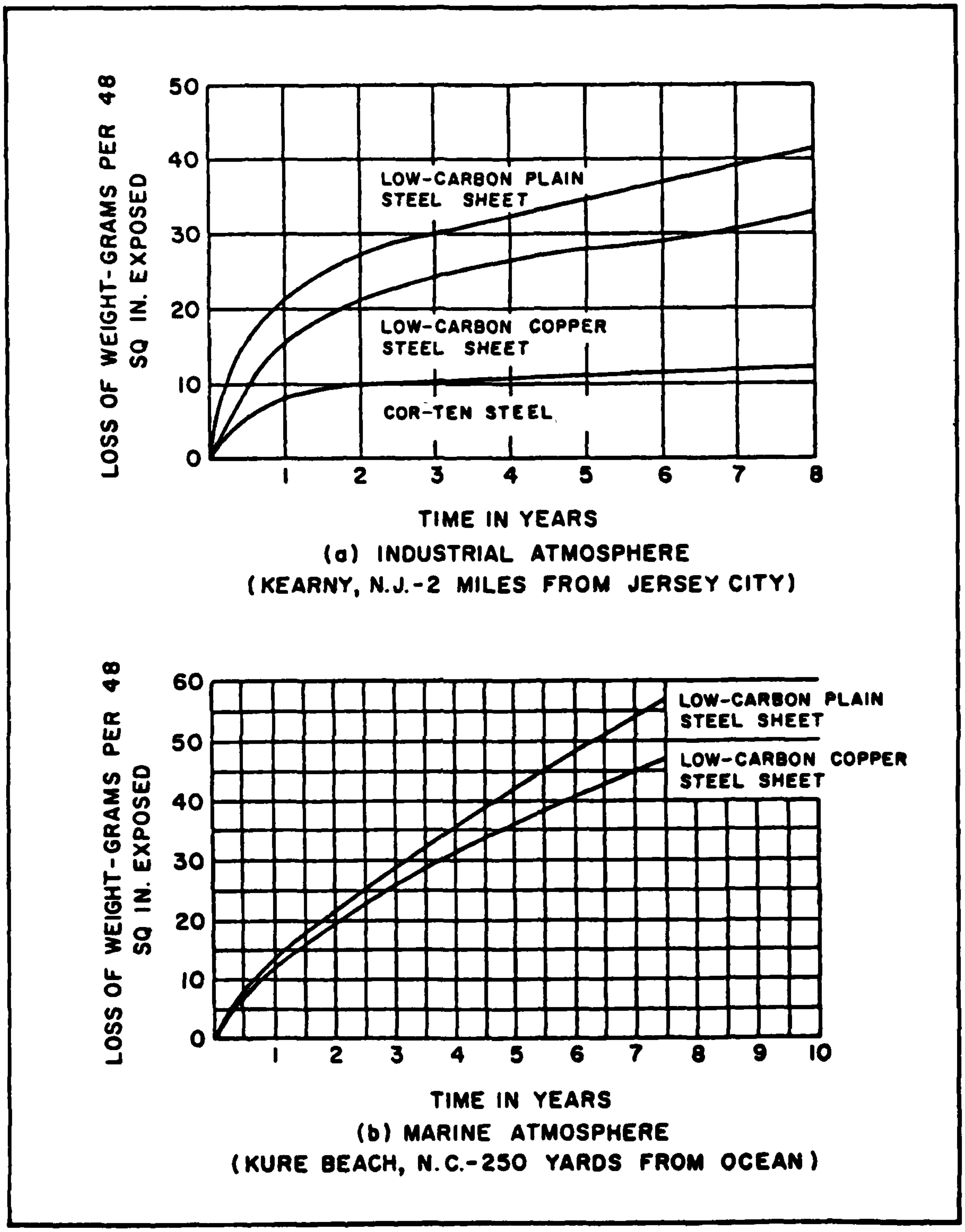

FIGURE 1
Time-Corrosion Curves for Industrial
and Marine Atmospheres

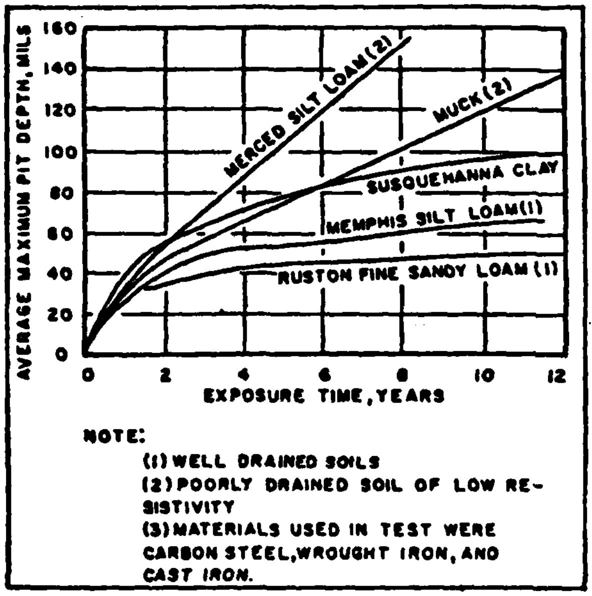

FIGURE 2
Time-Corrosion Curves in Soils

(5) Steel sheet piling for waterfront construction should be encased in concrete or given a protective coating to a minimum of 2 feet below mean low water level. Tie rods for sheet piling should be similarly protected for their entire length.

(6) Steel surfaces for open pier type construction should be given a protective coating as described above for steel sheet piling or shall be zinc-coated, or shall be encased in concrete.

(7) Where extreme corrosion conditions exist, consideration should be given to providing cathodic protection for steel piling exposed under water and tie rods for bulkhead construction in addition to protective coatings.

(8) If cathodic protection is not installed initially, consideration should be given to providing bonded cables for future connection for cathodic protection of the piling exposed under water.

(9) Structural members embedded in concrete and exterior railings, handrails, fences, guardrails, and anchor bolts shall be coated with zinc or coal tar enamel. Coating shall extend 6 inches outside of embedded portion. Where coated anchor bolts are used, consider reduction in bond strength when estimating pull-out resistance.

(10) Isolation of dissimilar metals (aluminum and steel are an example) shall be by use of fiber or plastic pads, by use of nonmetallic coatings, or other means as approved by NAVFACENGCOM HQ.

c. Use of Corrosion-Resistant Steel Conforming to ASTM A242 or A588. ("Weathering" Steels).

(1) Do not use in areas where the atmosphere contains salt spray. This applies even to locations remote from a body of salt water if experience demonstrates that the prevailing winds will carry salt-laden air into contact with the structure.

(2) Do not use in seawater environment. No benefit will derive. Plain carbon steel (ASTM A-36) is a better choice.

(3) Do not use in buried structures, unless coated.

d. Use of Corrosion-Resistant Steel Conforming to ASTM A690. (See DM-25.7 for requirements.)

e. Use of Stainless Steel (ASTM A306 and A316).

(1) Do not use in salt spray zone.

(2) Do not use if buried, or likely to become buried. In general, in an aqueous environment, if contact with oxygen is precluded, accelerated corrosion will occur. This happens under washers, for example.

3. WEAR.

a. Increase in Metal Thickness. Allow for wear by increasing the metal thickness of those portions of the design section subject to wear, beyond the stress requirements. The amount of such increase depends on the material to be handled and on the desired service life. Estimate wear requirements on the basis of previous experience or similar conditions (or both) at existing installations.

b. Wear Plates. Consider the use of replaceable wear plates where extremely severe wear conditions occur.

4. CLIMATIC REQUIREMENTS.

a. Arctic and Antarctic Zones. For carbon steel, the transition from ductile to brittle behavior occurs within temperatures to be expected in Arctic and Antarctic Zones. The lower ductility normally is not important but loss of impact resistance requires that structures subject to impact, such as bridges and crane runways, be designed with the following factors in mind:

(1) Avoidance of "stress raisers" is important. As examples:

(a) provide ample fillets.

(b) two thin plates with welds offset are better than one thicker plate with thicker weld.

(2) Welding is a particular problem. Use riveted or bolted joints, as feasible. Take precautions to eliminate gas and impurities in welds. Proper preheating and postcooling are essential.

(3) Low-carbon steels and nickel-alloy steel show better toughness at low temperature than do carbon steels.

b. Tropic Zones. The effects of increased temperatures, as in tropic zones, on the load capacity of steel members may be neglected.

5. ELEVATED TEMPERATURES.

a. Hot-Rolled Carbon Steel. Up to 500°F, strength of steel shall be assumed to be the same as the strength at normal temperature. Above 500°F, the yield strength shall be assumed to decrease linearly with increasing temperature up to 1,000°F, where the assumed yield point shall be assumed as 70 percent of the strength at 500°F.

b. High Strength and Heat Treated Steels. The effect of elevated temperatures on high strength and heat treated steels should be thoroughly investigated. For example, quenched and tempered materials will undergo radical changes in their mechanical properties as well as toughness when subjected to elevated temperatures.

c. See Table 1 for properties of steel at elevated temperatures.

TABLE 1
Properties of Steel at Elevated Temperatures

Type of Steel	Temperature °F	(°C)	Yield Strength 0.2% Offset ksi	(MPa)	Tensile Strength ksi	(MPa)	Percent Elongation in 2 in. (51mm)
ASTM A36	80	(25)	36.0	(250)	64.0	(440)	37
	300	(150)	30.2	(210)	64.0	(440)	25
	500	(260)	27.8	(190)	63.8	(440)	28
	700	(370)	25.4	(175)	57.0	(395)	35
	300	(480)	21.5	(150)	44.0	(305)	42
	1100	(595)	16.3	(110)	25.2	(175)	50
	1300	(705)	7.7	(55)	9.0	(60)	71
USS COR-TEN A ASTM A242	80	(25)	54.1	(375)	81.3	(560)	31
	200	(95)	50.8	(350)	76.2	(525)	31
	400	(200)	47.6	(330)	76.4	(525)	27
	600	(315)	41.1	(285)	81.3	(560)	24
	800	(425)	39.9	(275)	76.4	(530)	28
	1000	(540)	35.2	(240)	52.8	(365)	21
	1200	(645)	20.6	(140)	27.6	(190)	48
							in 1 in. (25 mm)
USS COR-TEN ASTM A588 (High-Temp)	80	(25)	58.6	(405)	78.5	(540)	30
	200	(95)	57.3	(395)	79.5	(550)	28
	400	(200)	50.4	(350)	74.8	(575)	24
	600	(315)	42.5	(290)	77.7	(535)	24
	800	(425)	37.6	(260)	70.7	(490)	25
	1000	(540)	32.6	(225)	46.4	(320)	26
	1200	(645)	17.9	(125)	23.3	(160)	48

S.I. Conversion Units

The following metric equivalences were developed in accordance with ASTM E 621 and are listed in the sequence as they appear in the text. All equivalences are approximate.

3 ft/sec/sec.	=	900 mm/sec/sec.
300 feet	=	90 m
.004 inch/year	=	0.1016 mm/year
3/8 inch	=	10 mm
500° F	=	260° C

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NAVFAC Documents and Standards. Government agencies may obtain documents from the U.S. Naval Publications and Forms Center, Philadelphia, Pennsylvania 19120. Telephone: AUTOVON-442-3321; commercial 215-697-3321. Non-government organizations may obtain documents from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

NAVFAC DM-2.1	General Requirements
NAVFAC DM-7	Soil Mechanics, Foundations and Earth Structures
NAVFAC DM-8	Fire Protection Engineering
NAVFAC DM-9	Cold Regions Engineering
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